Course Title: **Radiological Control Technician**
Module Title: **Internal Exposure Control**
Module Number: **1.12**

Objectives:

1.12.01 Identify four ways in which radioactive materials can enter the body.

1.12.02 Given a pathway for radioactive materials into the body, identify one method to prevent or minimize entry by that pathway.

1.12.03 Identify the definition and distinguish between the terms "Annual Limit on Intake" (ALI) and "Derived Air Concentration" (DAC).

1.12.04 Identify the basis for determining Annual Limit on Intake (ALI).

1.12.05 Identify the definition of "reference man".

1.12.06 Identify a method of using DACs to minimize internal exposure potential.

1.12.07 Identify three factors that govern the behavior of radioactive materials in the body.

1.12.08 Identify the two natural mechanisms which reduce the quantity of a radionuclide in the body.

1.12.09 Identify the relationship between the physical, biological and effective half lives.

1.12.10 Given the physical and biological half lives, calculate the effective half life.

1.12.11 Given a method used by medical personnel to increase the elimination rate of radioactive materials from the body, identify how and why that method works.

INTRODUCTION

Radiological control involves the protection of mankind and his environment from the harmful effects of exposure to radiation or radioactive materials. The tasks that make up the responsibilities of the RCT include those actions used to minimize the potential exposure of workers and include efforts at reduction of both internal and external exposures. This lesson is designed to familiarize the technician with those actions necessary to minimize the entry of radioactive materials into the body and the basis for those actions. Major topics include:

- Modes of entry into the body
- Preventive measures, their use, and their basis
- Metabolism of materials and elimination processes
- Assessment methods
- Definitions.

References:

1. "Basic Radiation Protection Technology"; Gollnick, Daniel; Pacific Radiation Press; 1983
2. "Reactor Health Physics Technology Course"; Gilchrist, R. L.; PNL; Richland, Wa.
3. DOE-STD-1098-99, "DOE Radiological Control Standard".
4. 10 CFR Part 835 (1998) "Occupational Radiation Protection".
5. "The Health Physics and Radiological Health Handbook," Scinta, Inc. 1989.

ENTRY OF RADIOACTIVE MATERIALS INTO THE BODY

1.12.01	*Identify four ways in which radioactive materials can enter the body.*

Knowledge of the ways in which radioactive materials enter the body is essential for two reasons. How radioactive material gets into the body must be known in order to design and implement measures to prevent entry. The mode of entry by which particular materials get into the body can influence the behavior of the materials.

Modes of Entry

Inhalation: Materials enter the body in the air that is breathed.

Ingestion: Materials enter the body through the mouth.

Absorption: Material enters the body through intact skin.

Entry through wounds:

(1) *Penetration:* Materials enter (passively) through existing wounds which were not adequately covered.

(2) *Injection*: Materials enter (forcefully) through wounds incurred on the job.

1.12.02	*Given a pathway for radioactive materials into the body, identify one method to prevent or minimize entry by that pathway.*

Preventive Measures

<u>Inhalation:</u> assessment of conditions, use of engineering controls, respiratory protection equipment

<u>Ingestion:</u> proper radiological controls and work practices

<u>Absorption:</u> assessment of conditions and protective clothing

Entry through wounds: not allowing contamination near a wound by work restriction or proper radiological controls if an injury occurs in a contaminated area.

Note that the preventive measures are designed to do one of two things: (1) minimize the amount of radioactive materials present which are available to enter the body, or (2) block the pathway from the source of radioactive materials into the body.

1.12.03	*Identify the definition and distinguish between the terms "Annual Limit on Intake" (ALI) and "Derived Air Concentration" (DAC).*
1.12.04	*Identify the basis for determining Annual Limit on Intake (ALI).*
1.12.05	*Identify the definition of "reference man".*
1.12.06	*Identify a method of using DACs to minimize internal exposure potential.*

ANNUAL LIMIT ON INTAKE AND DERIVED AIR CONCENTRATION

Assimilation of radioactive materials in the workplace occurs most often as a result of inhalation of airborne radioactive contaminants. With some nuclides, specifically tritium, absorption through the skin is also a major concern. To ease the control in the workplace, two limiting values have been calculated and are available for use in limiting the inhalation of radioactive materials. These limiting values are: Annual Limit on Intake (ALI) and Derived Air Concentration (DAC).

Annual Limit on Intake is the quantity of a single radionuclide which, if inhaled or ingested in one year, would irradiate a person, represented by reference man (ICRP Publication 23), to the limiting value for control of the workplace.

Derived Air Concentration is the quantity obtained by dividing the ALI for any given radionuclide by the volume of air breathed by an average worker during a working year ($2.4E3m^3$). The derivation of the Annual Limit on Intake is based on known metabolic processes for the nuclides involved and reference man.

Reference man defines the physiological makeup of an average man in terms of factors required for dose calculations and includes such items as height and other dimensions, mass, size and mass of organs. The metabolic processes are specific to the chemical and physical (solubility, particle size, etc.) form of the nuclide when they are known. When they are not known, the worst case information, or the most conservative conditions, are used. With all of this information and the limitations on the amount of dose allowed, the amount of a particular nuclide that would result in that dose can be calculated. The resulting quantities are the values that are listed for Annual Limits on Intake.

According to ICRP 23, reference man breathes at an average rate of 20 liters per minute, or 0.02 m^3/min. In the course of one working year, the total volume breathed would be:

$$\frac{0.02\ \text{m}^3}{\text{min}} \times \frac{60\ \text{min}}{\text{hr}} \times \frac{8\ \text{hrs.}}{\text{day}} \times \frac{5\ \text{days}}{\text{week}} \times \frac{50\ \text{weeks}}{\text{year}} = 2400\ \text{m}^3$$

As stated above, the DAC is equal to the ALI divided by the volume of air breathed by the average worker during a working year; that is:

$$DAC = \frac{ALI}{2400\ m^3}$$

10 CFR 835 "Occupational Radiation Protection," Section 1003 "Workplace Controls" states:

> During routine operations, the combination of physical design features and administrative controls shall provide that:
>
> (a) The anticipated occupational dose to general employees shall not exceed the limits established at § 835.202; and
>
> (b) The ALARA process is utilized for personnel exposures to ionizing radiation.

The mentioned subpart E (835.403 "Area Monitoring") establishes the requirements for air monitoring in the workplace. It states:

> (a) Monitoring of airborne radioactivity shall be performed:
>
> > (1) Where an individual is likely to receive an exposure of 40 or more DAC-hours in a year; or
> >
> > (2) As necessary to characterize the airborne radioactivity hazard where respiratory protective devices for protection against airborne radionuclides have been prescribed.
>
> (b) Real-time air monitoring shall be performed as necessary to detect and provide warning of airborne radioactivity concentrations that warrant immediate action to terminate inhalation of airborne radioactive material.

For control purposes within the facilities, we can take several preventive actions using these DAC values. Obviously, the measures used to minimize the concentration of airborne contaminants that exist remain the primary means of minimizing potential exposure. Minimizing the concentrations to below DAC values helps insure that workers could not exceed the ALI even if they were in the area continuously for long durations and breathing air at those concentrations. In fact, 10 CFR 835 defines Airborne Radioactivity Areas as any area, accessible to individuals, where: (1) The concentration of airborne radioactivity, above natural background, exceeds or is likely to exceed the derived air concentration (DAC) values listed in appendix A or appendix C of Part 835; or (2) An individual present in the area without respiratory protection could receive an intake exceeding 12 DAC-hours in a week. Section 835.603 states that the words "Caution, Airborne Radioactivity Area" or "Danger, Airborne Radioactivity Area" shall be posted at each airborne radioactivity area.

Minimizing the stay of workers in airborne areas to short periods of time and augmenting installed engineering controls with respiratory protection equipment are two ways to reduce the concentration of contaminants in the air the workers are actually breathing.

The limitations imposed, in terms of dosage to exposed workers, are expressed as an annual limit. 10 CFR 835 does not specifically establish monthly or quarterly limitations; conceivably, a worker could be allowed to receive his/her full allocation of dose in a single event. In practice, this is not acceptable. Concentrations of contaminants in the air are monitored by continuous monitoring equipment and are supplemented by grab sampling as required. Engineering controls are augmented with respiratory protection equipment when airborne contaminants exceed or potentially exceed DAC values.

MOVEMENT OF RADIOACTIVE MATERIALS THROUGH THE BODY

1.12.07 Identify three factors that govern the behavior of radioactive materials in the body.

Unlike external exposure monitoring, there is no simple device which can be placed on or in the body to determine the quantities of radioactive materials in the body or the dose received by the individual as a result of irradiation of body tissues by these materials. Thus, when radioactive material enters the body, the assessment methods must be based on what happens to the materials, or what the body does with them.

Knowledge of normal metabolic processes within the body can be applied to radioactive materials. The body does not possess the ability to differentiate between a non-radioactive atom and a radioactive atom of the same element. Therefore, in terms of metabolic processes, the material is handled the same way.

Once the material is in the body, then its behavior is governed by the chemical form, its location in the body, and the body's need for that material.

- **Chemical form**: solubility
- **Location**: pathways
- **Body's need**: intake and incorporation vs. elimination.

Intake and Uptake

Two terms that are used frequently when discussing the entry of radioactive materials into the body are *intake* and *uptake*. Though sometimes used interchangeably, there is a difference between them.

Intake: the amount of radionuclide taken into the body

Uptake: the amount of radionuclide deposited in the body which makes its way into the body fluids or systemic system (i.e. blood).

Uptake is an older term used with earlier lung models used in assessing maximum permissible body burdens (ICRP 2). Intake is a newer term used with newer reference man models in ICRP Publications 26 and 30. (Intake is defined in the 10 CFR 835 Internal Dosimetry Program Implementation Guide).

NORMAL METABOLIC PATHWAYS FOR MATERIALS IN THE BODY

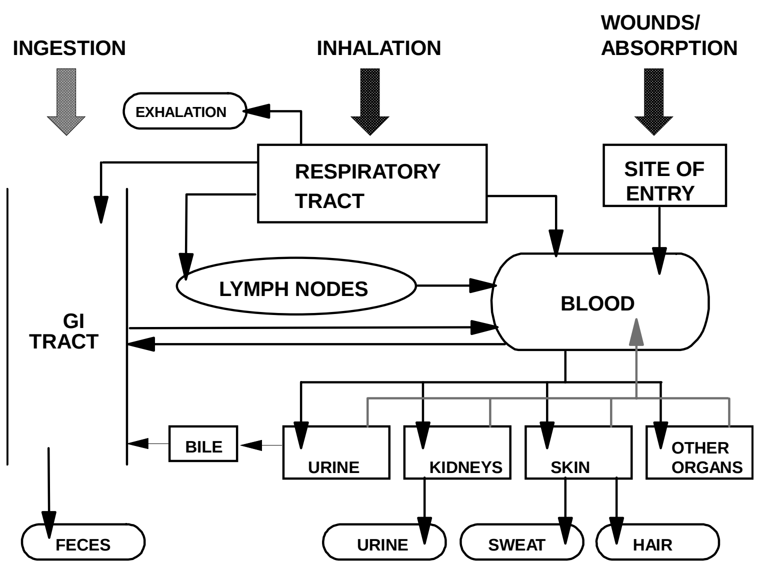

FIGURE 1. Metabolic Pathways

Inhaled Radioactive Materials

General pathways are

- Exhalation
- Deposition in lungs with eventual transfer to GI tract or retention
- Transport to body fluids
- Transfer to lymph nodes with eventual movement to body fluids
- Retention in lymph nodes.

Once in the bodily fluids, possibilities include:

- Transfer to specific organ
- Filtration and elimination by kidneys
- Transport and removal from body fluids through circulatory systems (perspiration)

Insoluble particulates

- Lung retention time based on particle size and density
- Removal in mucous to digestive tract
- Elimination in fecal waste

Soluble particulate materials

- Retention in lungs based on size and density - some exhalation
- Some removed to GI tract for elimination or to body fluids
- Transfer to body fluids via lymph nodes or directly from lungs
- Some retention in lymph nodes
- Body fluids to tissue or organ of interest
- Excretion

Ingested Radioactive Materials

For elements not used by the body, absorption by ingestion is poor, and most materials will pass straight through the body. Materials pass through stomach to small intestine where transport of soluble materials to body fluids will occur. From body fluids, materials go to the organs and/or are removed through normal biological elimination processes.

Soluble Materials

- Transfer to body fluids in intestines
- Circulation, absorption, incorporation in tissues and organs
- Elimination in urine

Insoluble Materials

- Passes straight through
- Elimination in feces

Absorbed Radioactive Materials

Many radioactive nuclides have been reported as absorbable through the skin. These nuclides include tritium, iodine, and some of the transuranics in an acidic form. Except for tritium, most of these do not pose any considerable concern because of the relative percentages absorbed as opposed to entry through inhalation. The most important of these is tritium as water vapor (e.g. if you were surrounded by a cloud of tritium existing as water vapor, the ratio of exposure of absorption through the skin vs inhalation is 1:1). Once absorbed into the body, tritium exchanged freely with hydrogen, disperses throughout the body almost immediately, and irradiates bodily tissues throughout the body.

Target Organs

Some elements are collected in target organs. As an example, iodine is collected by the thyroid gland. Major dose to the thyroid could be expected as a result of gamma and beta interactions emitted by iodine collected in the thyroid gland. The radiation emitted from iodine in the thyroid also can irradiate other nearby parts of the body. Gamma radiation can penetrate tissue very easily and cause interactions in parts of the body in which no iodine is located. Since all the iodine in the body is not in the thyroid gland, other parts of the body would also be irradiated as the iodine circulates throughout the body.

Other elements are processed differently. Some are distributed freely throughout body fluids. Some are collected in specific organs such as the kidneys, spleen or bone. Some materials which enter as particulate materials may spend the majority of their stay in the body in the lungs and are excreted through the digestive tract. Knowledge of material behavior is critical to assessing parts of the body affected and subsequent impact to the health of the individual involved.

1.12.08	*Identify the two natural mechanisms which reduce the quantity of a radionuclide in the body.*
1.12.09	*Identify the relationship between the physical, biological and effective half lives.*
1.12.10	*Given the physical and biological half lives, calculate the effective half life.*

NATURAL ELIMINATION PROCESSES

Once radioactive materials enter the body, there are two mechanisms which result in reduction of the quantities present.

Normal Biological Elimination

Radioactive materials that have been incorporated by biological functions into the body tissues and organs are eliminated from the body as are their non-radioactive counterparts. These materials are eliminated through the normal biological elimination processes of exhalation, perspiration, urination, and defecation. In most instances, when the body is not overwhelmed, biological elimination follows first order kinetics. In other words, each element has a measurable *biological half-life* which is the time required to reduce the amount of material in the body to one-half of its original value. If the body functions are overwhelmed, they are considered to be saturated. During the time period in which the body is saturated, the elimination rates may be vastly different and the concept of a biological half-life is not applicable. The biological half-life is independent of the physical or radiological half-life. Examples of measured biological half-lives include ^{3}H - 10 days and ^{60}Co - 9.5 days. (Note: these values will change slightly from one reference to another.)

Radioactive Decay

Each radioactive nuclide has a distinctive decay rate which is not influenced by any physical process, including biological functions. The amount of time required for one half of the material in the body to decay is called the radiological or *physical half life*. Radioactive decay will result in reduction of the quantity of the original nuclides deposited in the body. However, it is important to remember that the daughters of these nuclides may also be radioactive. Since most decay processes result in the transformation of one element to another, it is quite likely that decay processes would introduce completely different concerns for internal dose assessments.

Effective Half-life

The combined processes of biological elimination and physical decay result in the removal of radioactive materials at a faster rate than the individual reduction rate produced by either method. This means that:

$$T_e < T_b, T_p$$

The removal rate as a result of the combined processes is measured as an effective half-life and is calculated using the following formula:

$$T_e = \frac{T_b \times T_p}{T_b + T_p}$$

where: T_e = effective half-life
T_b = biological half-life
T_p = physical half-life

Another way that this is expressed is the *effective removal constant*, λ_e, which is the composite of the physical decay constant λ_p and the biological elimination constant λ_b.

$$\lambda_e = \lambda_b + \lambda_p$$

EXAMPLE 1.12-1

Determine the effective half-life of tritium if the biological half-life is 10 days and the physical half-life is 12.3 years.

Solution found at the end of this module.

EXAMPLE 1.12-2

Determine the effective half-life of ^{59}Fe if the biological half-life is 2000 days and the physical half-life is 44.56 days.

Solution found at the end of this module.

1.12.11	*Given a method used by medical personnel to increase the elimination rate of radioactive materials from the body, identify how and why that method works.*

MEDICAL ELIMINATION-RATE INCREASE METHODS

Once the presence of radioactive material in the body is known, there are steps that can be taken by medical personnel to increase the elimination rates (biological), thus reducing the dose received as a result of the intake/uptake. **The important thing to remember about the use of any materials discussed below is that these methods *should be used only under the direction of a licensed physician*.**

Blocking Agents

A *blocking agent* saturates the metabolic processes in a specific tissue with the stable element and reduces uptake of the radioactive forms of the element. As a rule, these must be administered prior to or almost immediately after the intake for maximum effectiveness and must be in a form that is readily absorbed. The most well known example of this is stable iodine, as potassium iodide, which is used to saturate the thyroid gland, thus preventing uptake of radioactive iodine in the thyroid.

Diluting Agents

A *diluting agent* is a compound which includes a stable form of the nuclide of concern. By introducing a large number of stable atoms, the statistical probability of the body incorporating radioactive atoms is reduced. A good example is increasing water intake following ^{3}H exposure. Diluting agents can also involve the use of different elements which the body processes in the same way. This type of treatment is called *displacement therapy*. A common form of this is the use of calcium to reduce deposition of strontium. The compound used must be as readily absorbed and metabolized as the compound that contains the radioisotope.

Mobilizing Agents

A *mobilizing agent* is a compound that increases the natural turnover process, thus releasing some forms of radioisotopes from body tissues. Usually most effective within two weeks after exposure; however, use for extended periods may produce less dramatic reductions.

Chelating Agents

A *chelating agent* is a compound which acts on insoluble compounds to form a soluble complex ion which can then be removed through the kidneys. Commonly used to enhance elimination of transuranics and other metals. Therapy is most effective when begun immediately after exposure if metallic ions are still in circulation and is less effective once metallic ions are incorporated into cells or deposited in tissue such as bone.

Common chelating agents include EDTA and DTPA

- CaNa-2 EDTA - commonly used in cases of lead poisoning, also effective against zinc, copper, cadmium, chromium, manganese, and nickel

- CaNa-3 DTPA - transuranics such as plutonium and americium

Diuretics

Diuretics increase urinary excretion of sodium and water. Diuretics are used to reduce internal exposure, however its use has been limited. Applications could include ^{3}H, ^{42}K, ^{38}Cl and others. Diuretics can lead to dehydration and other complications if not performed properly.

Expectorants and Inhalants

These are used to increase flow of respiratory tract excretions. Thus far this type of therapy has not been proven successful in removing radioactive particles from all areas of lungs.

Lung Lavage

This method involves multiple flushing of lungs with appropriate fluid to remove radioactive materials in the lungs. Usually limited to applications where resulting exposures would result in appearance of acute or subacute radiation effects.

SAMPLE PROBLEM SOLUTIONS

Sample Problem 1.12-1

$$\frac{12.3\ yrs}{1} \times \frac{365.25\ days}{1\ yr} = 4492.6\,days$$

$$T_e = \frac{10\ days \times 4492.6\ days}{10\ days + 4492.6\ days}$$

$$T_e = 9.9978\ days$$

Sample Problem 1.12-2

$$T_e = \frac{2000\ days \times 44.56\ days}{2000\ days + 44.56\ days}$$

$$T_e = 43.589\ days$$

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